Illuminating Au nuclei with ρ mesons.

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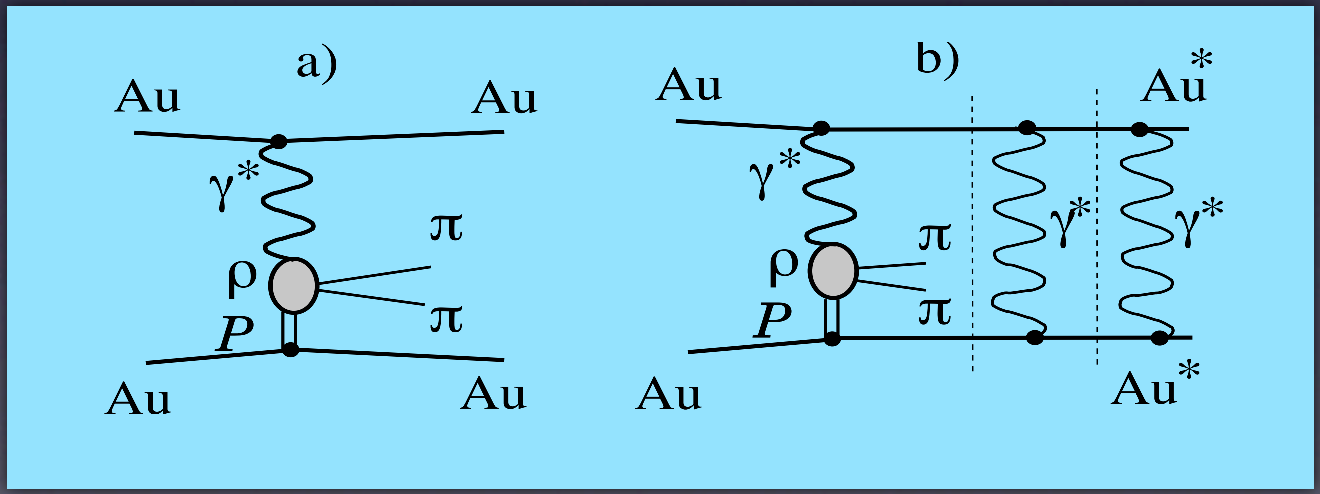
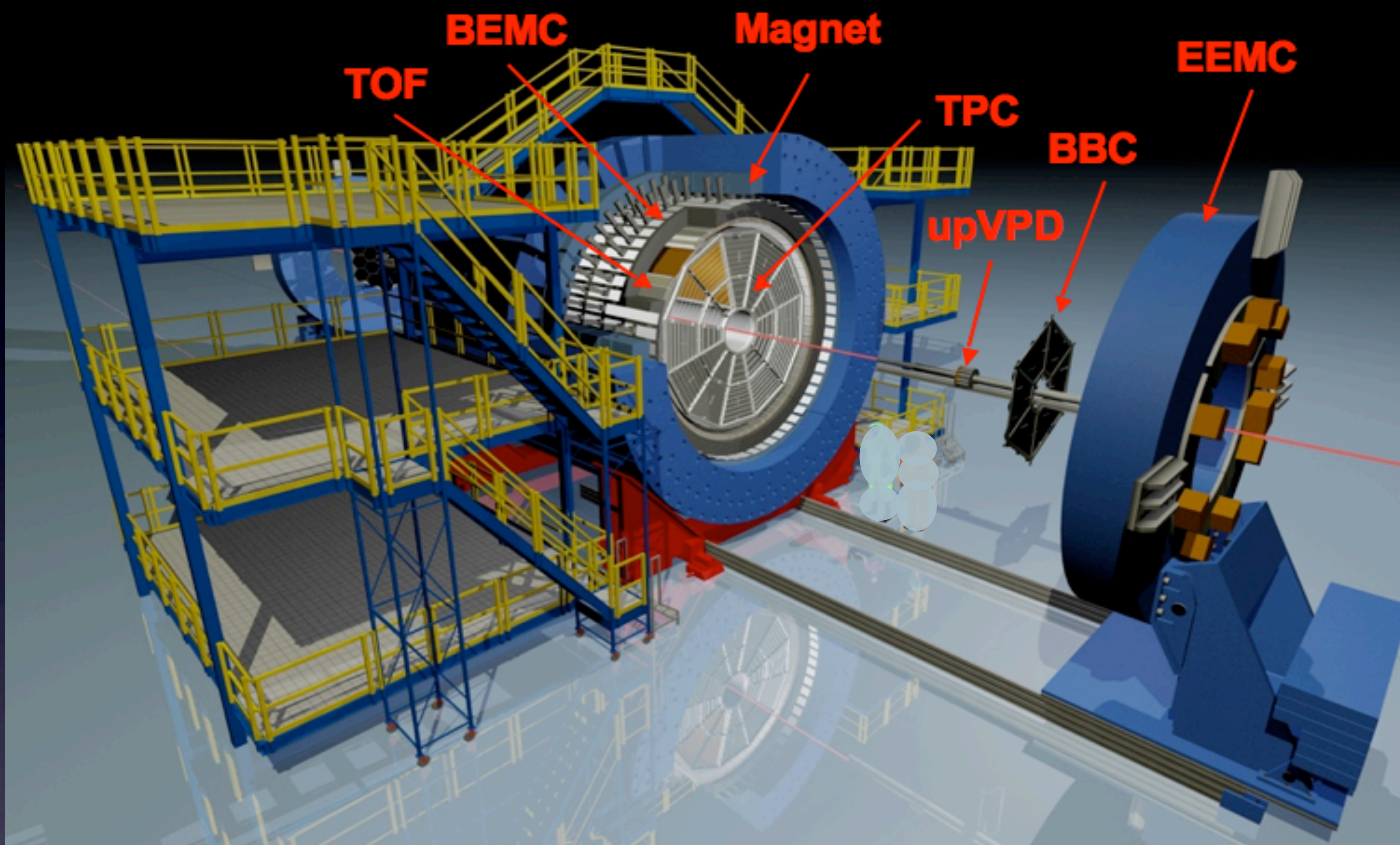
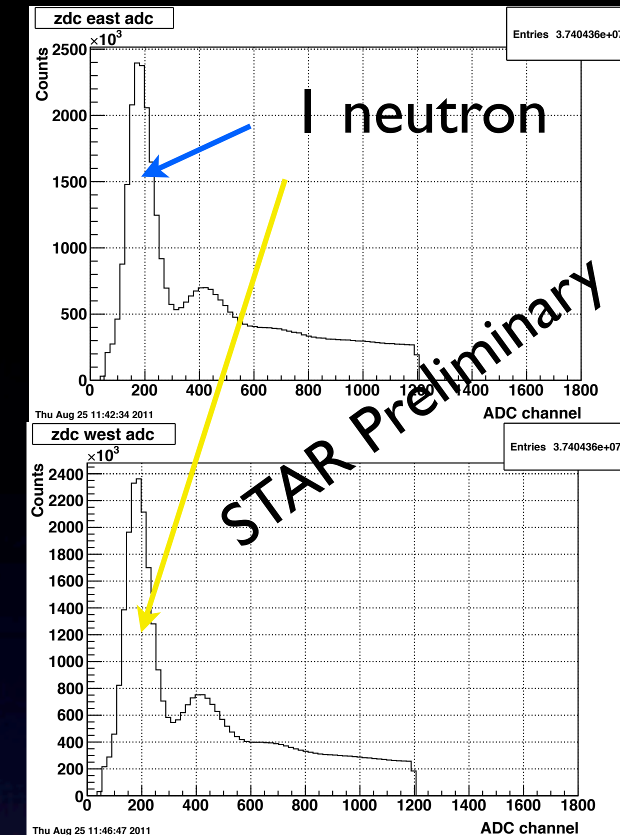
APS DNP Fall Meeting OCT 2011

The STAR Ultra Peripheral Collisions at RHIC studies glancing ($b>2R_A$ no hadronic interaction) heavy ion interactions at high energies, Au+Au at $\sqrt{s_{nn}}$=200 GeV for this report.
EM fields of Au ions (z=79), highly contracted by Lorentz boosts (γ=106.6) establish the only interaction between the ions. These fields are viewed as a strong flux of photons.
Exchanged photons fluctuate into quark-antiquark dipoles which interact with the target ion.
At RHIC energies the coupling between the dipole and the target is dominated γ + Pomeron where the Pomeron is described as a gluon system with vacuum quantum numbers.



Our data sample contains events collected with two triggers:
a) Au ions remain intact after interaction.
b) Au ions re-interact and emit a single neutron. Data presented here were collected with this trigger.





ZDC

UPC Main:

1 neutron in both ZDCs
Low multiplicity in |y|<1 selected with TOF
Veto charged particles at high rapidity (BBC)

UPC Topo

Low multiplicity in |y|<1 selected with TOF
Back to back hits in TOF sectors (excluding vertical cosmic rays
Veto charged particles at high rapidity (BBC)

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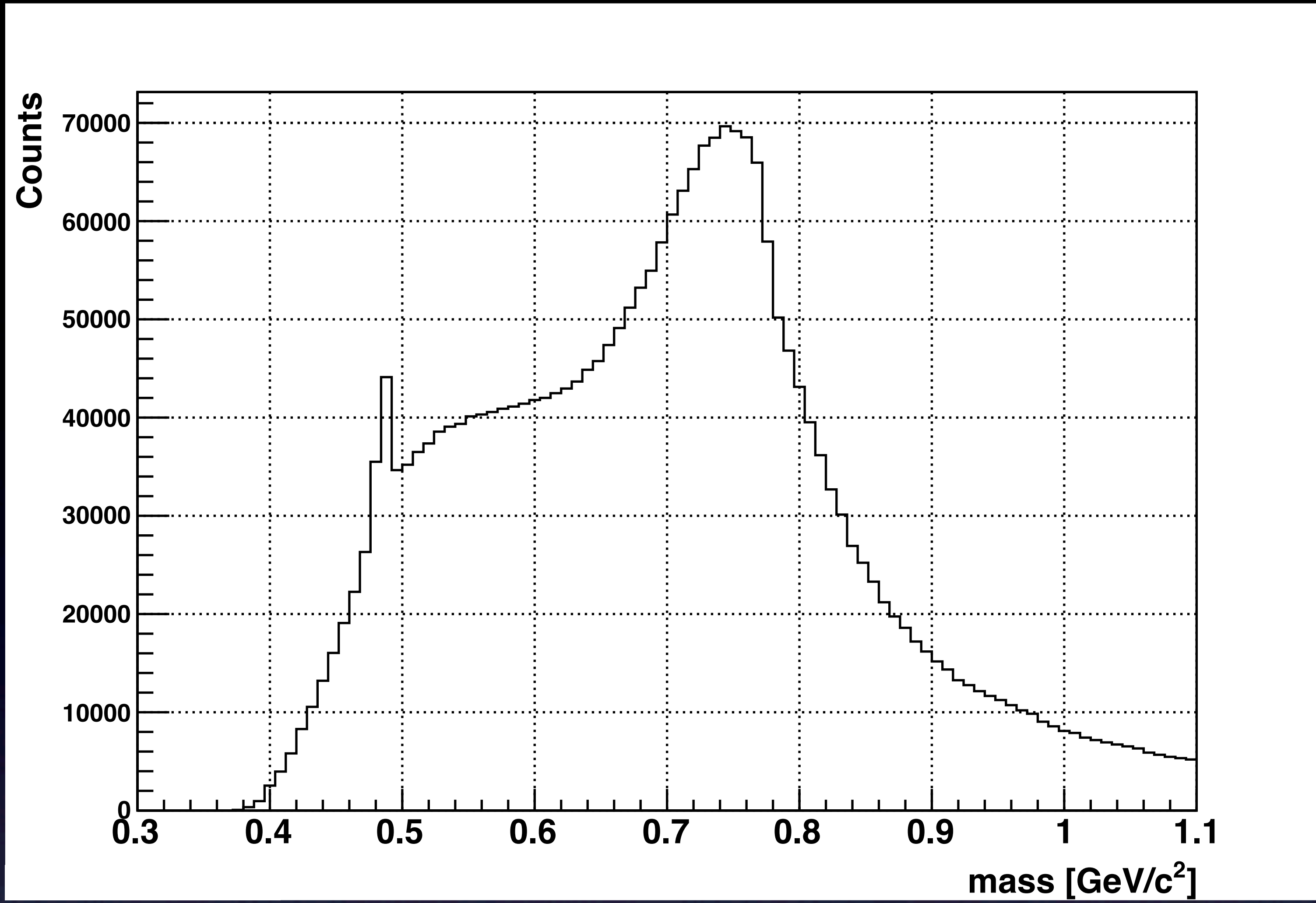
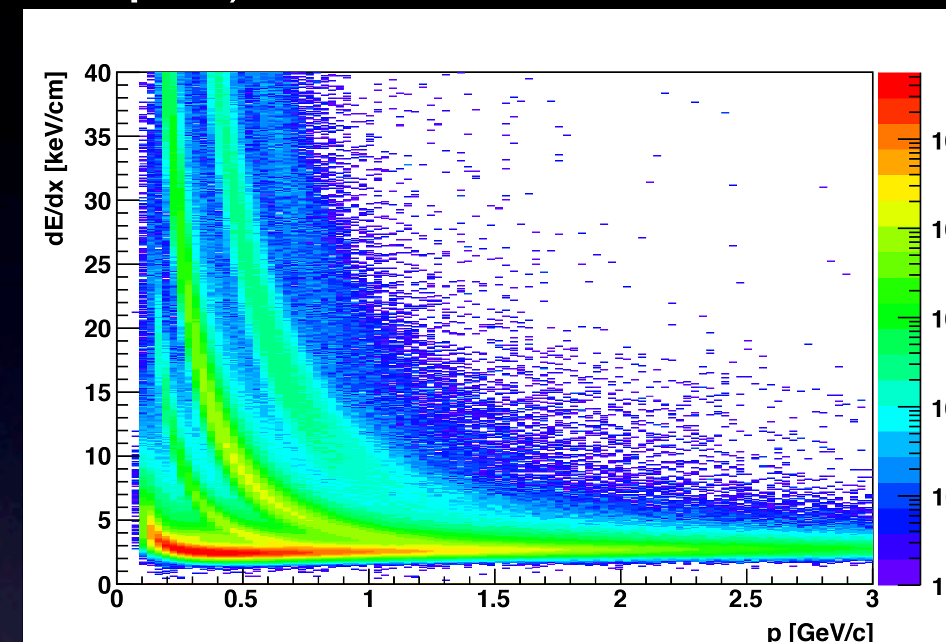
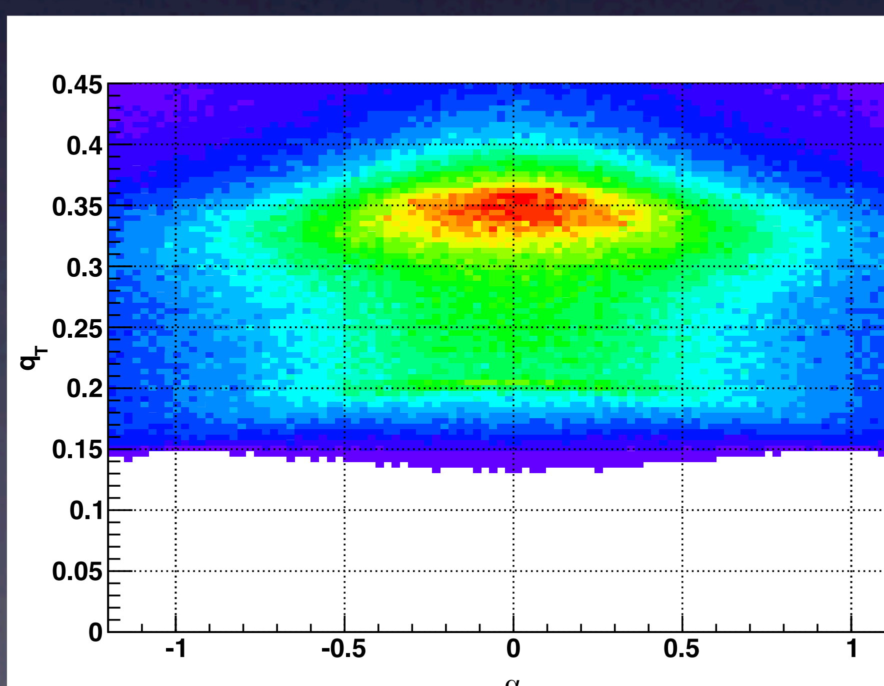
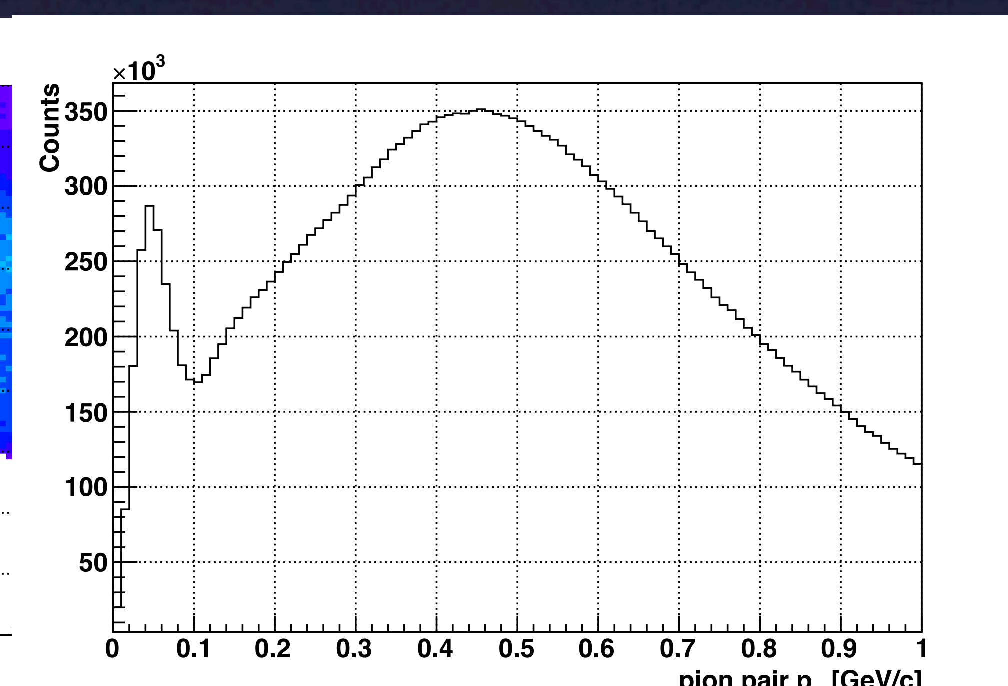


ρ mesons are reconstructed from their decay into 2 π. The π identification is done using the sampling of ionization energy loss in the TPC gas. (up to 45 samples)





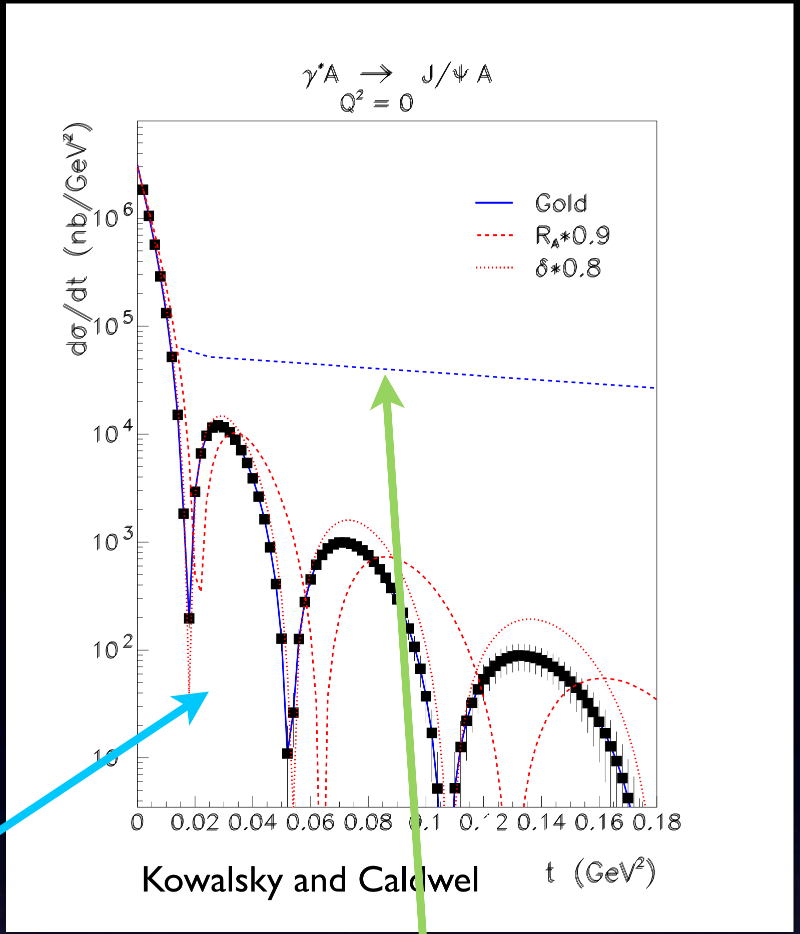


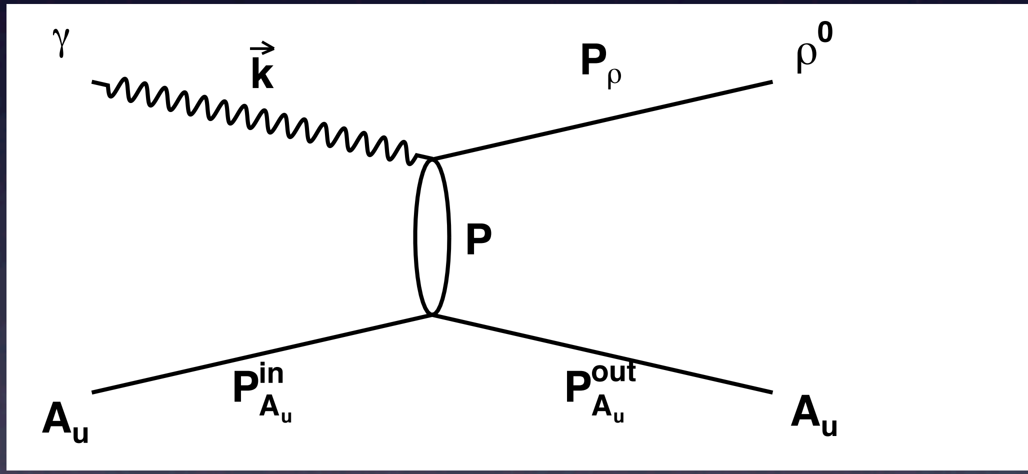
The STAR TPC may have more than one event for every readout. We use the vertices to correlate tracks to the TOF slats that formed the trigger.

We form pairs with tracks originating from vertices with less than 8 tracks.

We calculate the invariant mass of opposite charge pions to select our ρ candidates.

Elastic scattering of the the dipole (which tends to be preferably a vector meson) on the target ion produces a **diffraction pattern** determined by its spatial distribution. Because of the coupling to the Pomeron we are extracting the **spatial distribution of glue in Au nuclei.**



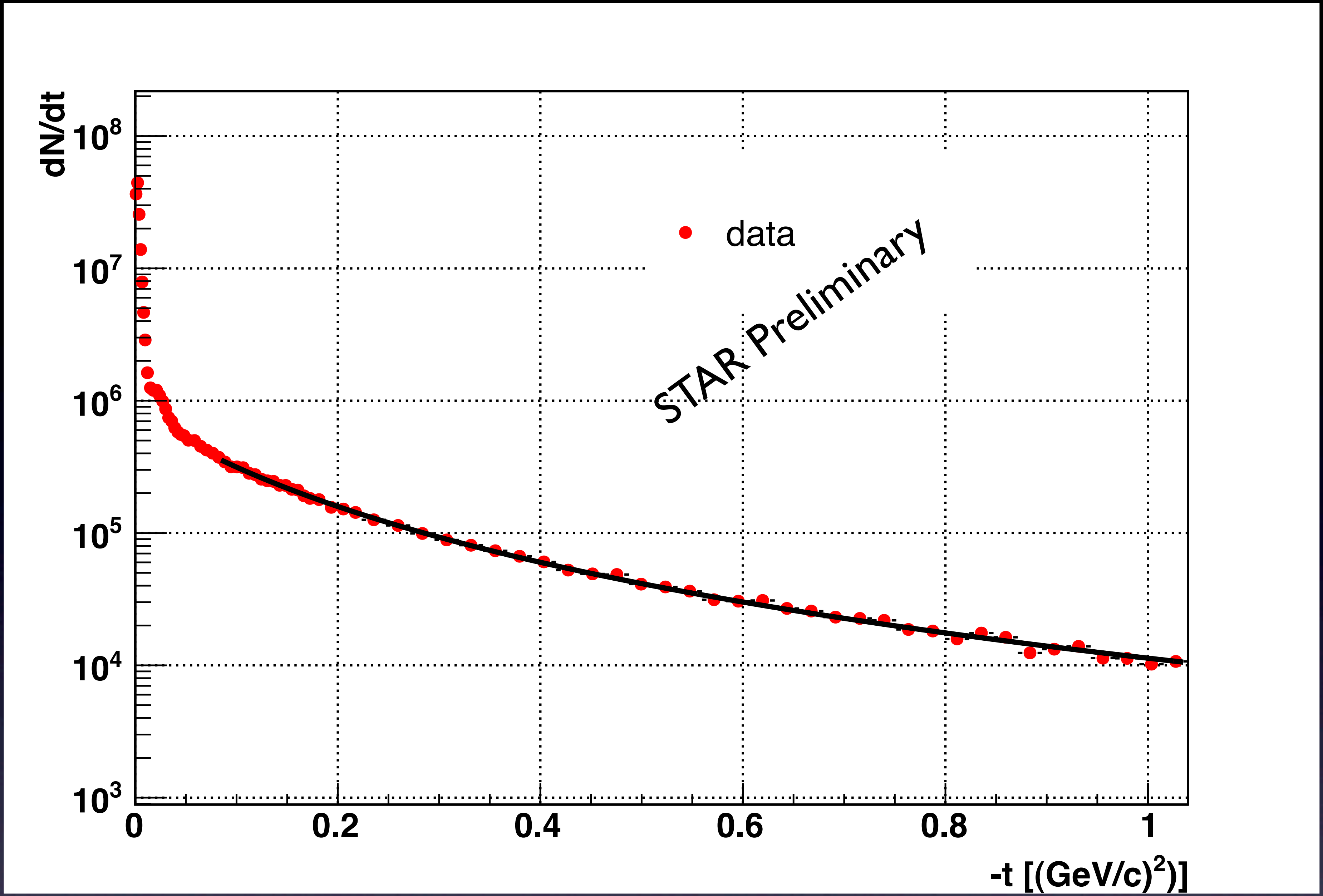


Coherent interaction with the whole A nuclei

Incoherent interaction (with individual nucleons)

First order kinematics:
the γ is completely longitudinal.
Transverse momentum of ρ balances the p_T of outgoing Au

New interest on similar measurements in e+A colliders has spurred some theoretical work: Diffraction with J/Ψ to study spatial distribution or density effects.



A power law shape reproduces the “incoherent” part of our dN/dt distribution.

Clean ρ candidates: only two opposite charge tracks per vertex, 1 neutron in both ZDCs, cut in ρ invariant mass, at least 26 hits per track.

p_T > 150 MeV on pion tracks to minimize acceptance x efficiency effects.

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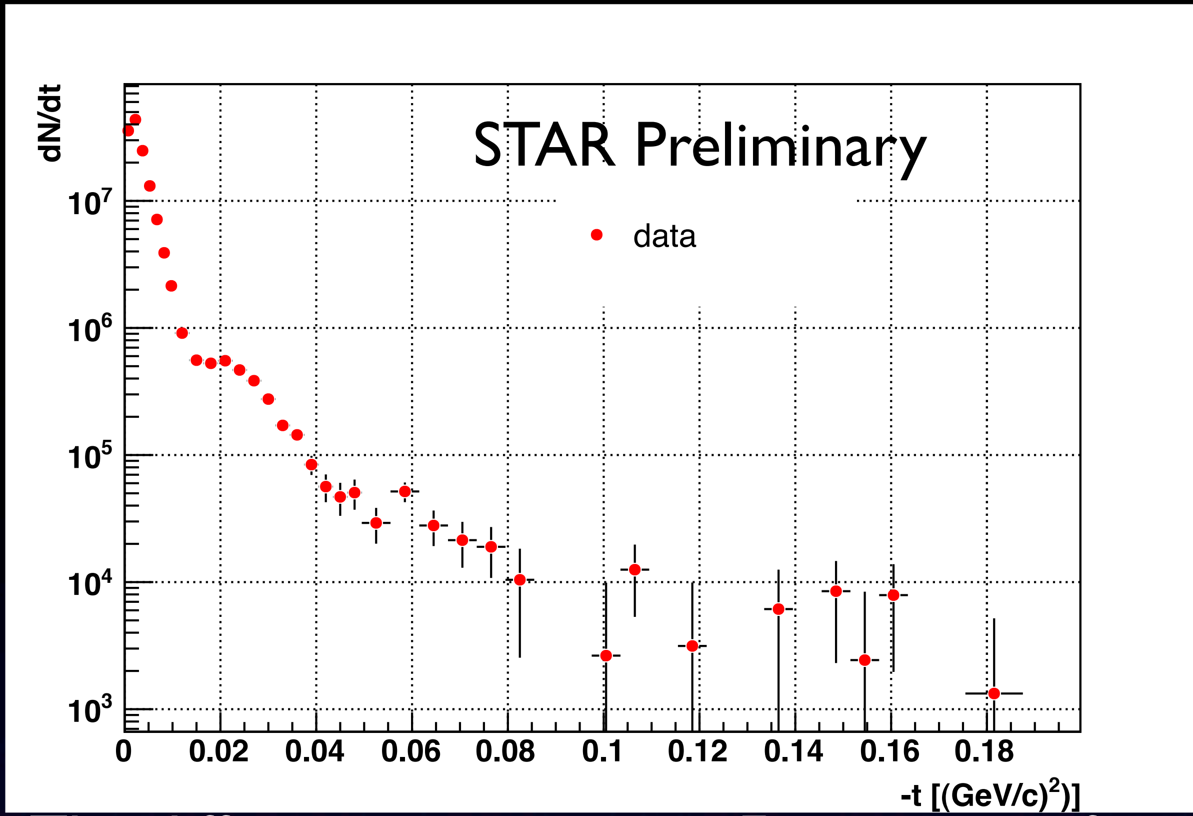
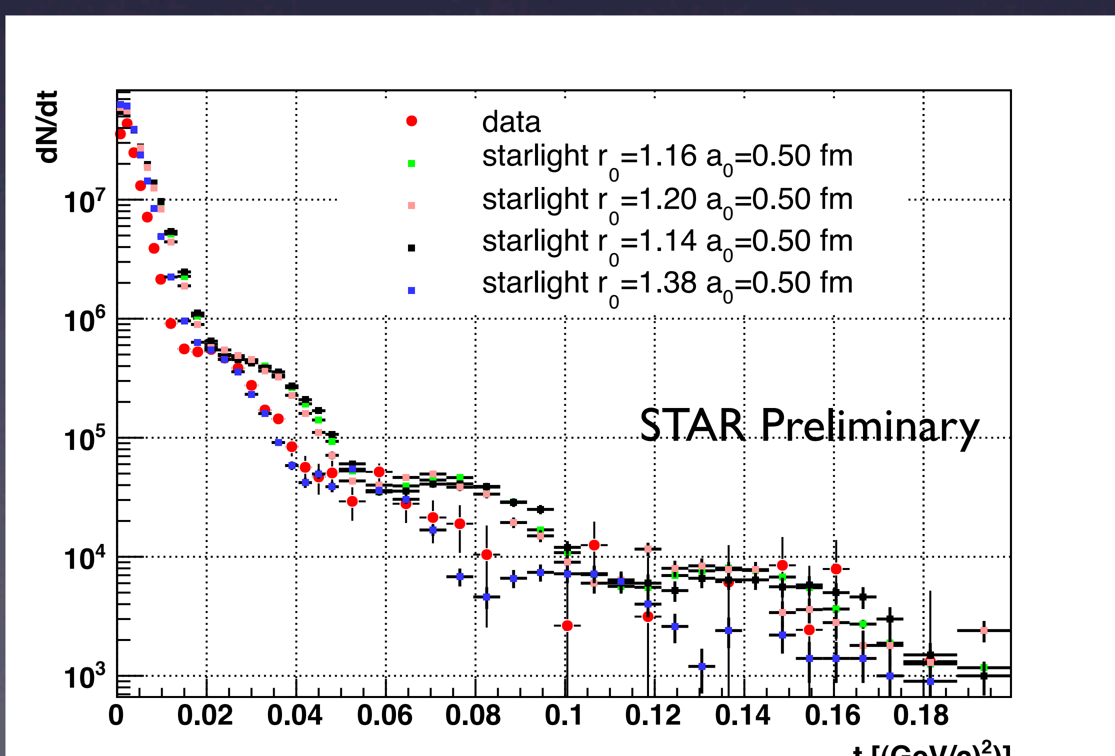
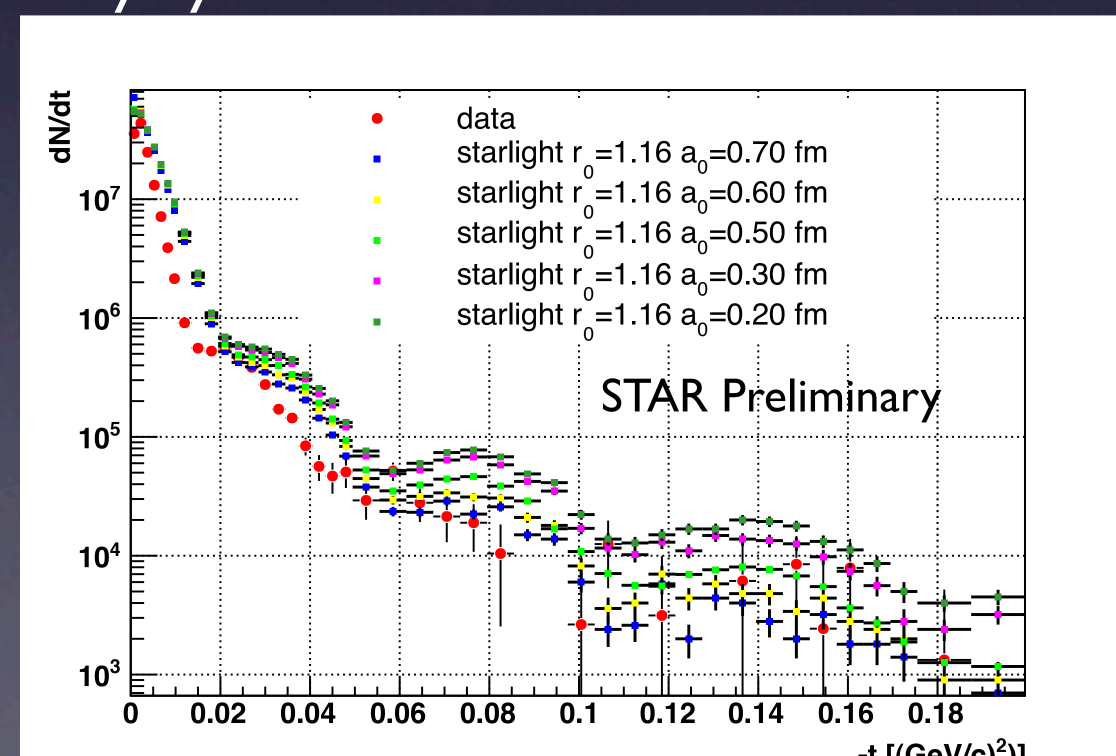
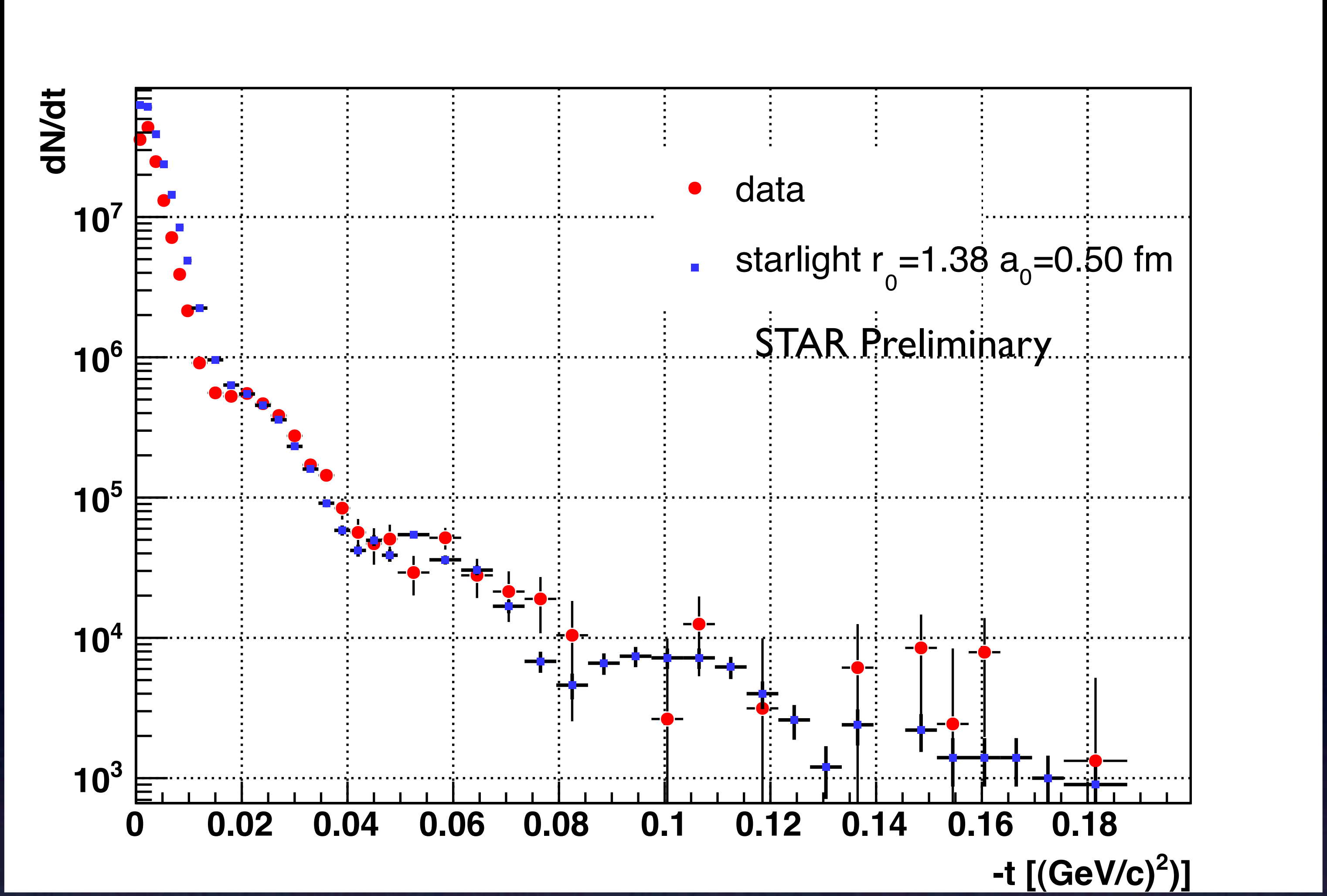


Once the incoherent part of the distribution is subtracted, the first three peaks of the diffraction pattern are discernible.

The diffraction pattern is a Fourier transformation of the spatial distribution of the target as function of impact parameter b. The spatial distribution in our event generator is based on a disk with radius: $R = r_0 A^{1/3}$ with $r_0 = c(1 - c / A^{2/3})$. A Yukawa potential ($e^{-r/a_0}/r$) shape defines the edge of the disk. The values of r_0 and a_0 are changed to generate several samples of 10 million events each. We select the values that match the data. This exercise has been done by eye.







The best agreement between data and StarLight is found for r_0 = 1.38 fm and a_0 = 0.5 fm

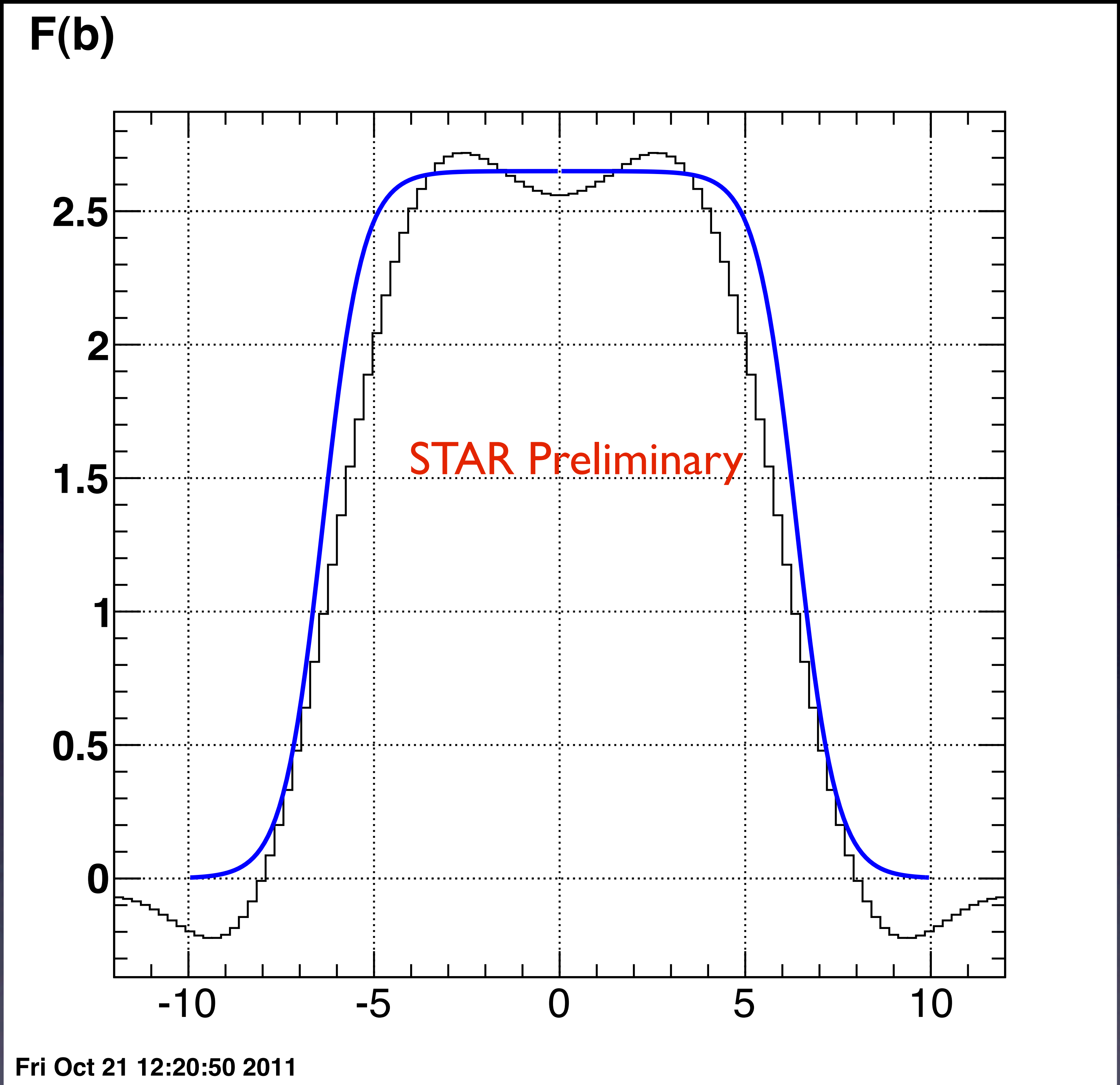
The value for the Au radius obtained with this match may indicate that we do not yet have a proper treatment for the kinematics or the reaction:

- We know so far that the contribution of $t_{||}$ is small.
- Should we include a transverse component to the γ momentum?
- What is the range of the Pomeron?

We are currently investigating other possible sources of distortion in the data (backgrounds, incoherent component subtraction, etc.)

- Or the measurement is already close to its final stage but the actual radius of Au at high energy has grown beyond the values measured at low energy. T. Kodama et al. Phys. Rev. C 53, 501 (1996)

Another way to extract a "density function"



FWHM of this distribution corresponds to R ~ 6 fm

Blue curve: Wood-Saxon with electron scattering results.

Feeding the measured distribution to a Fourier-Bessel transform:

$$f(b) = \int_0^{2\sqrt{t_{max}}} \sqrt{F(x^2)} J_0(xb/\hbar c) \frac{x}{2\pi} dx$$

produces a result that is much closer to previous measurements.

Nucleus	A	R	a	w
C	12	2.47	0	0
O	16	2.608	0.513	-0.051
Al	27	3.07	0.519	0
S	32	3.458	0.61	0
Ca	40	3.76	0.586	-0.161
Ni	58	4.309	0.516	-0.1308
Cu	63	4.2	0.596	0
W	186	6.51	0.535	0
Au	**197**	**6.38**	**0.535**	**0**
Pb	208	6.68	0.546	0
U	238	6.68	0.6	0

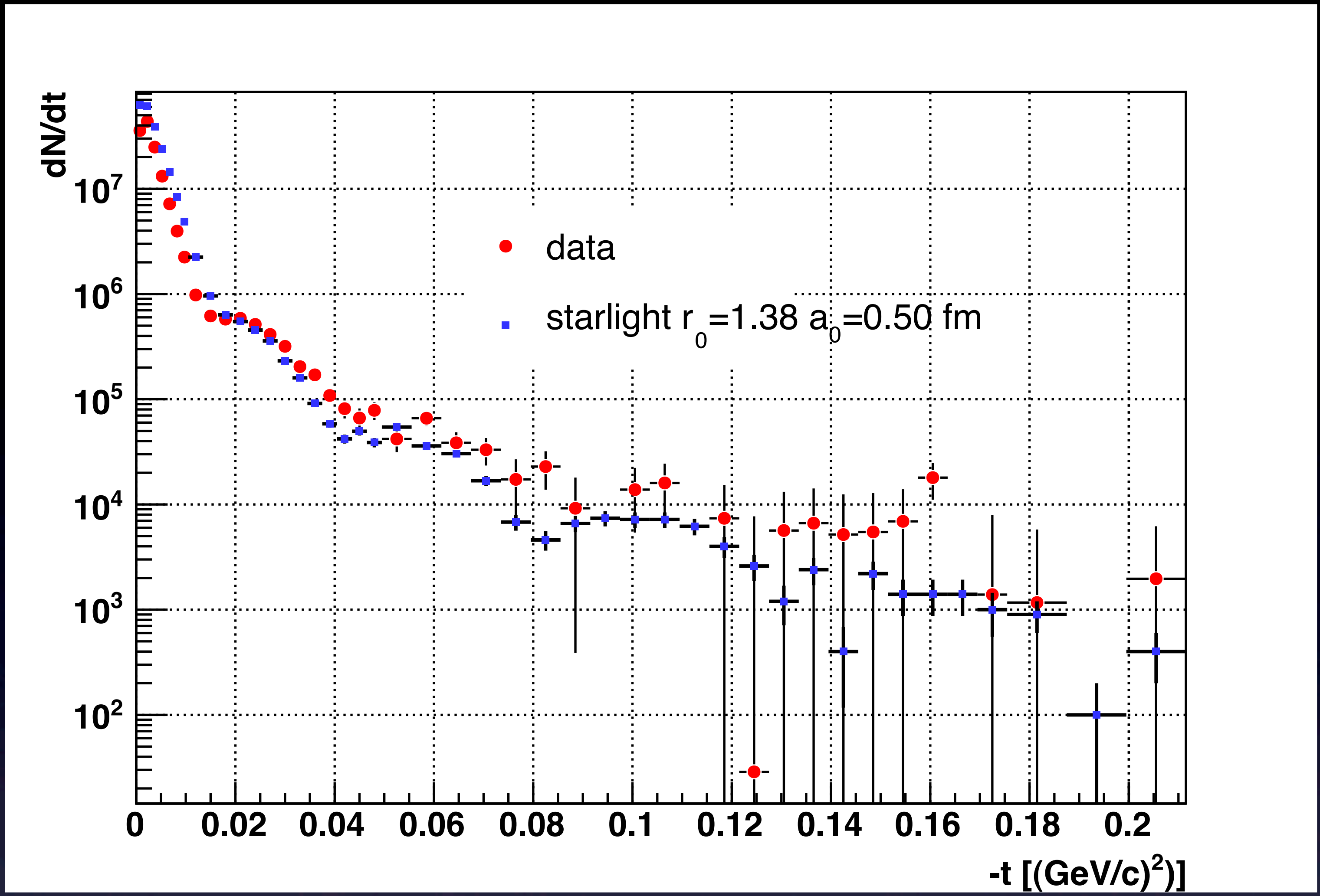
H. DeVries, C.W. De Jager, C. DeVries, 1987
ATOMIC DATA AND NUCLEAR DATA TABLES 36,495536 (1987)

This result obtained comparing preliminary data and the event generator StarLight is to be compared to R=6.38 fm extracted from electron scattering measurements.).
This analysis has just started. We are working on the extraction of the ρ meson detection efficiency from the embedding of pion pairs
from a ρ decay into actual STAR events.
We are also identifying all possible source of systematic uncertainties on our future results.
We may also be measuring a growth of nuclei radius with energy.

Summary and plans

The main message of this report is:

- Scattering of ρ mesons produced in UPC events at RHIC can be used to study coherent diffraction off nuclei.
- More work is needed to identify backgrounds.
- In order to extract cross sections we need to extract efficiency X acceptance corrections for ρ detection.
- We need to find the best way to extract the spatial distribution of the target. Fits to the data or use of event generators.
- Once we accomplish that we need to estimate our systematic uncertainties.



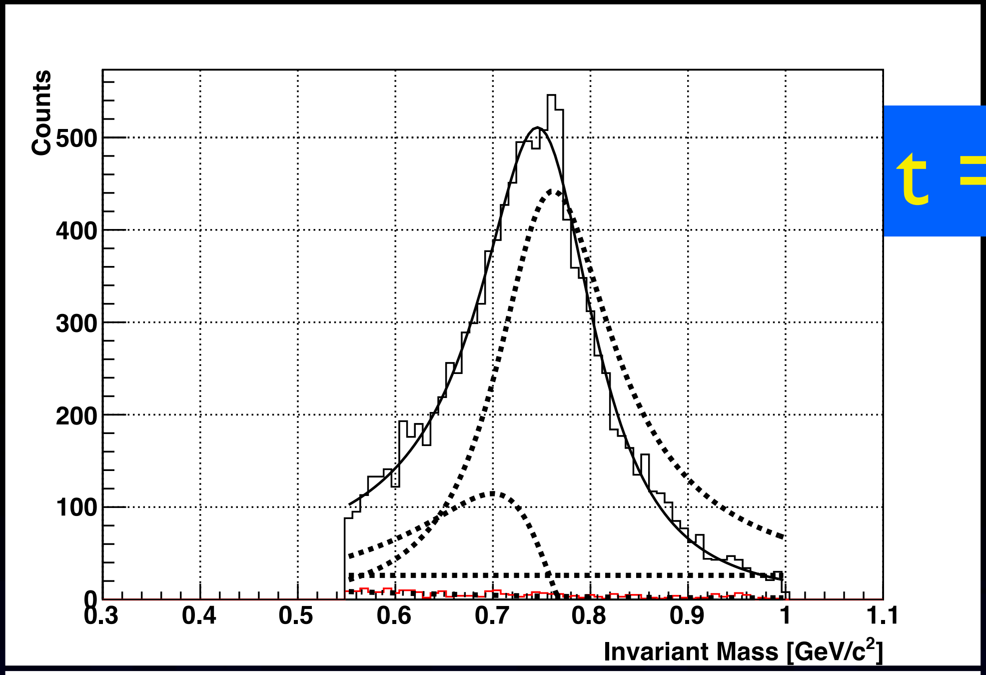
This distribution in t includes background subtraction; the background
is estimated using equal sign pairs in the same t bins.

We also subtract the "incoherent" component after we fit it to a power law above t=-0.2 GeV2

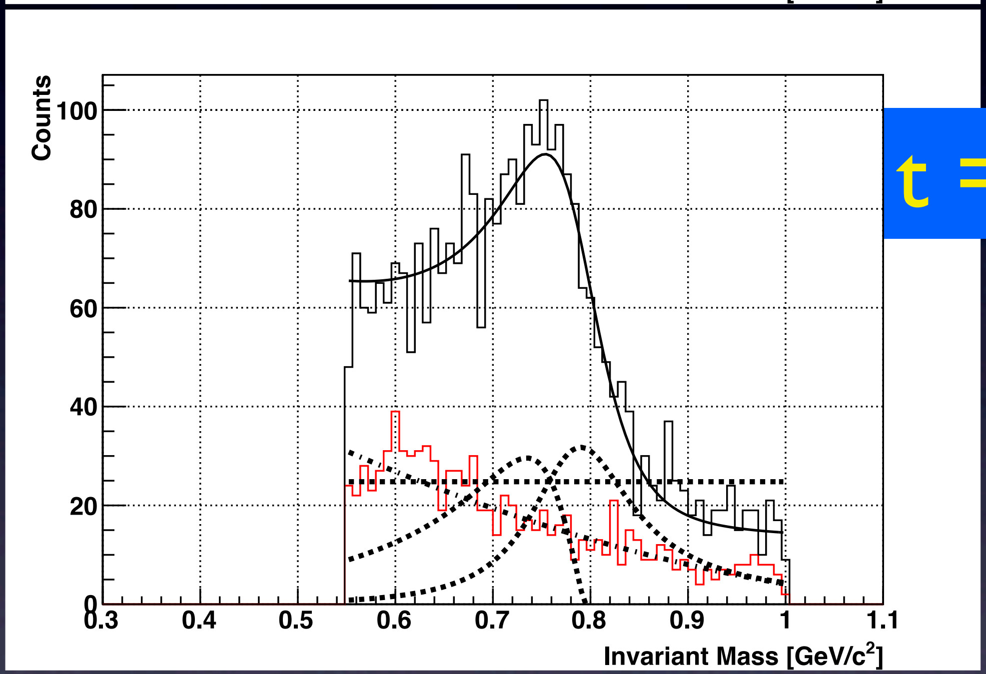
Invariant mass for pairs in different t bins.

Equal sign pairs are counted in the red histograms (background).

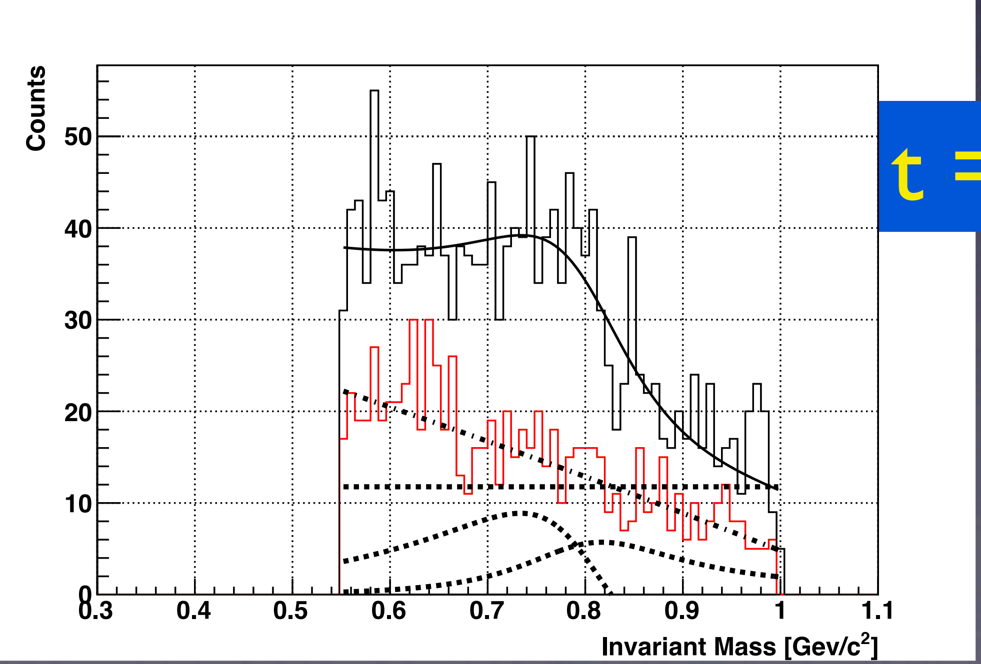
t =-0.00275



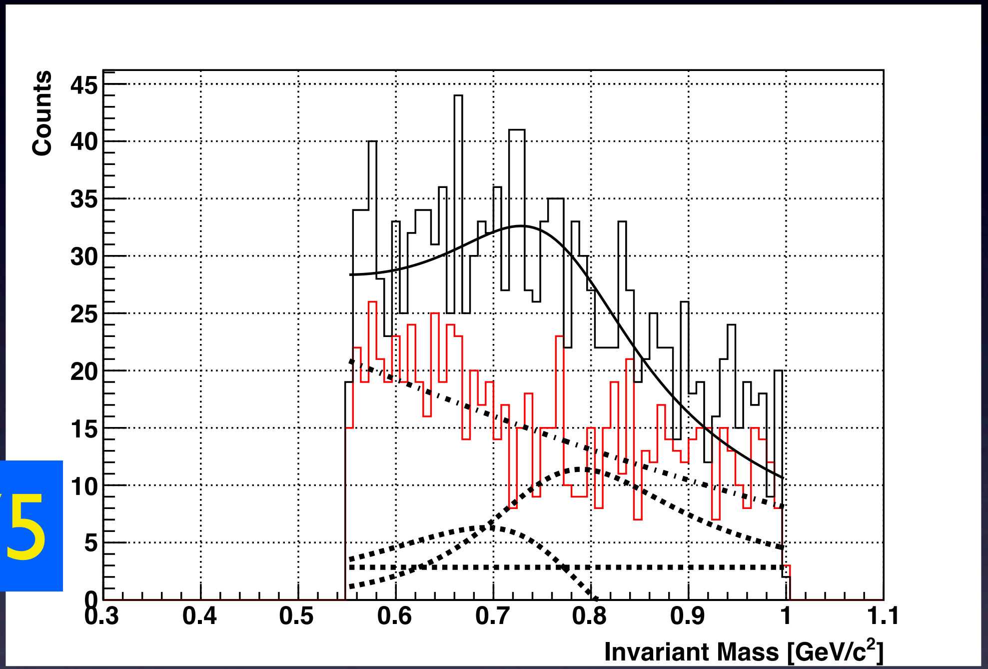
t =-0.0165



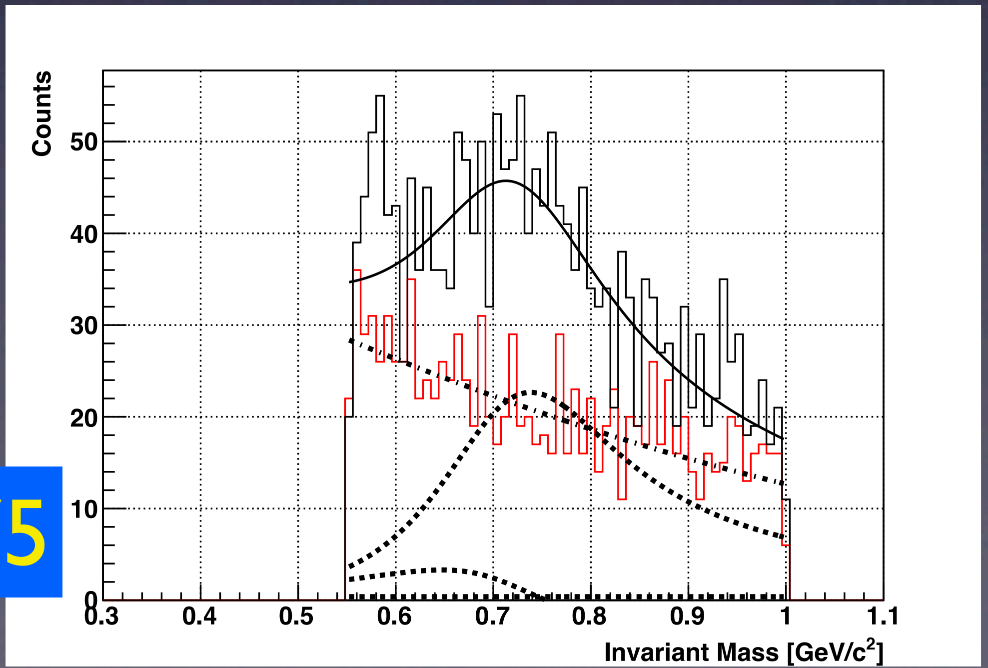
t =-0.21675



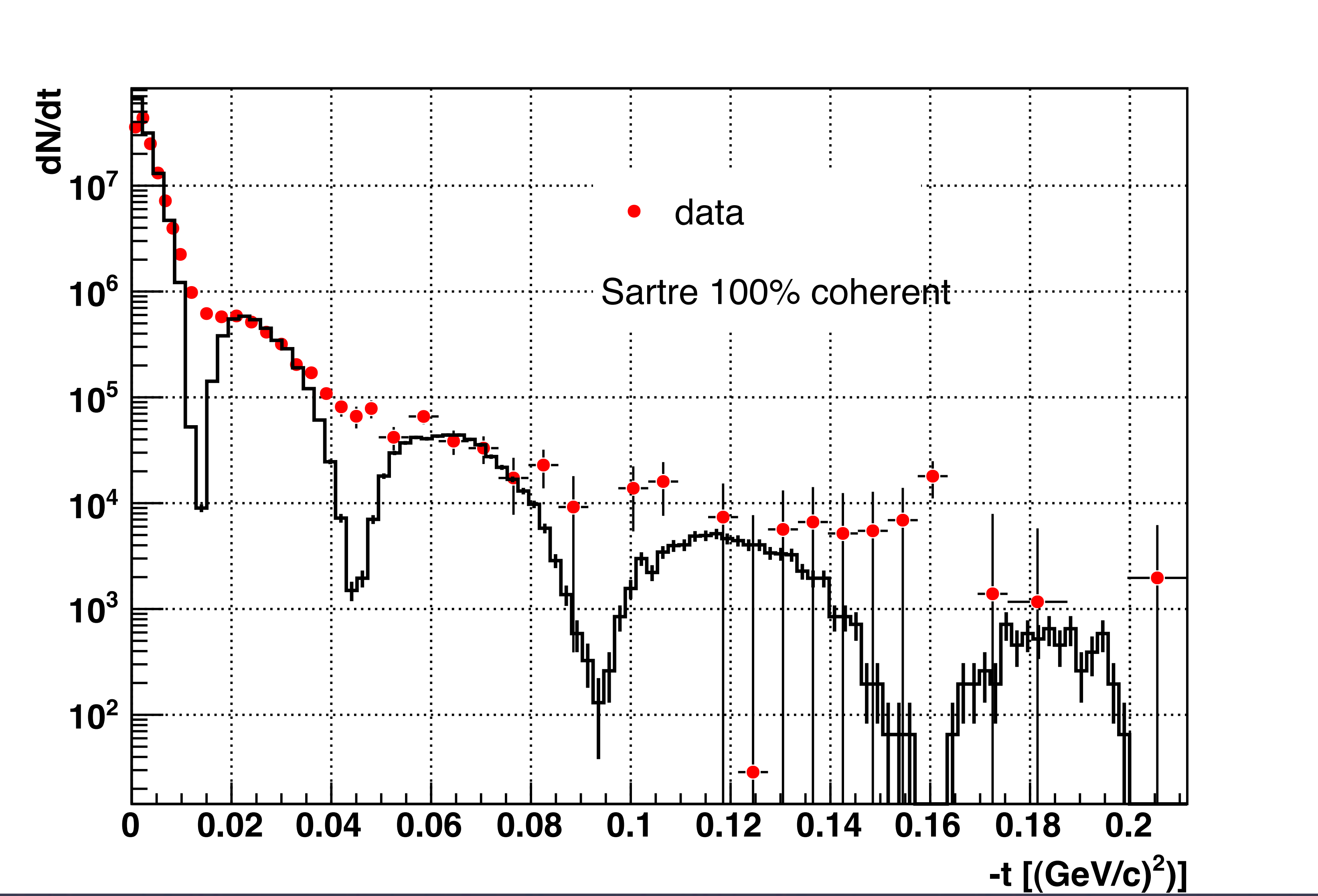
t =-0.27675



t =-0.93375



Comparison to e+A event generator Sartre



Sartre is run with electron and Au ions at 100 GeV.

The flux of virtual photons is not the same as in Au + Au, it is expected that an overall normalization would take care of that difference.

The agreement between data and Sartre is good, specially the location of the first and second dips. The match of the slope of the first peak and the magnitude of second and third one is also remarkable.

Sartre Au W-S parameters:
R = 6.38 fm
a=0.5 fm
ρ_0 = 0.1693 fm^{-3}

Backup

$$P_\gamma + P_A^{in} = P_\rho + P_a^{out}$$

The Mandelstam variable t can be written two ways:

$$t = (P_\rho - P_\gamma)^2 = (P_A^{out} - P_A^{in})^2$$

$$t = (E_\rho - E_\gamma)^2 - (\vec{k} - \vec{p_\rho})^2$$

$$t = -\vec{p_{\rho T}}^2 - (\vec{k} - \vec{p_{\rho\|}})^2$$

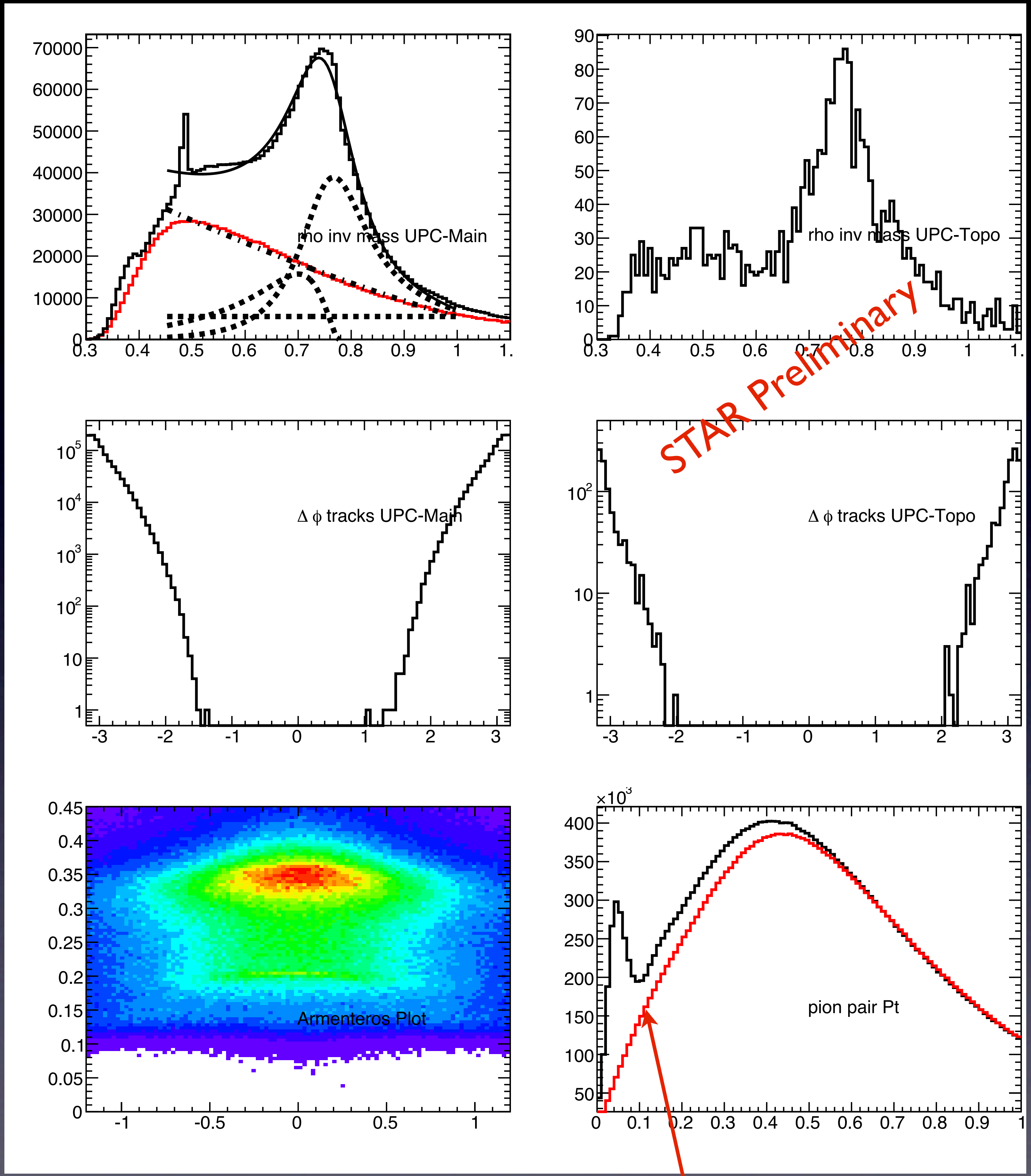
$t = t_T + t_\|$ with $t_T = -\vec{p_{\rho T}}^2$

and $t_\| = -(\vec{k} - \vec{p_{\rho\|}})^2$

In the CM frame $t_\| = -M_\rho^4/4k^2$, the momentum of the photon can be extracted from the rapidity of the ρ meson: $y = ln(2k/M_\rho)$

$t_\|$ in the target nuclei rest frame is then:

$$t_\| = -M_\rho^2/(2\gamma e^{|2y|})$$



Equal sign pion pairs used to estimate background